UNITED STATES PATENT APPLICATION FOR:

DUAL-BEAM INTERFEROMETER FOR ULTRA-SMOOTH SURFACE TOPOGRAPHICAL MEASUREMENTS

INVENTORS:

JIANMIN WANG
JASON L. PRESSESKY
LI-PING WANG

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Peter L. Brewer
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MOSER, PATTERSON & SHERIDAN, LLP
3040 Post Oak Blvd., Suite 1500
Houston, Texas 77056
Phone: 713-330-4844
Fax: 713-623-4846

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RELATED APPLICATIONS

[0001] This new application for letters patent claims priority from an earlier-filed provisional patent application entitled. That application was filed on June 17, 2003 and was assigned Application No. 60/479,294.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to characterization of a flat surface. More specifically, the present invention pertains to the use of an optical interferometer to analyze the flatness of a flat surface. Further still, the present invention presents an apparatus and method for profiling a smooth surface, such as the surface of a magnetic recording disc.

Description of the Related Art

[0003] The computer industry employs magnetic discs for the purpose of storing information. In this respect, computer systems employ disc drive systems for transferring and storing large amounts of data between magnetic discs and the host computer. The magnetic discs are typically circular in shape, though other shapes are used. One or more discs may be used in a disc drive system, depending on the needs of the system and the capacity of the drive.

[0004] It is desirable that the surface of a magnetic disc be as flat as possible. Uniform flatness aids in maintaining a constant fly-height of the slider, where the magnetic read/write head operates over the disc surface. This, in turn, ensures accurate writing/reading of magnetic data by the read/write head to and from the disc. Flat surface topography also allows the slider and attached magnetic head to fly more closely to the disc surface, permitting a tighter concentration of magnetic data to be embedded in the disc. Thus, periodic surface characterization of magnetic discs is part of the quality control employed in the manufacturing process.

[0005] In order to accurately analyze surface topography in ultra-smooth surfaces, it is known to use an optical interferometer. An optical interferometer is a tool that provides the unique advantages of non-contact operation, high resolution, wide spatial frequency coverage and high throughput. However, conventional interferometers are extremely sensitive to environmental vibration.

[0006] In a conventional interferometer, the surface topography is inferred by measuring the optical path length difference between an object beam and a reference beam. The reference beam length is usually fixed to be a constant length. Environmental vibration can cause body movement between the interferometer and the test object, which in turn can introduce a spurious change of optical path length in the object beam. Stated another way, if the disc surface experiences vertical vibration, the optical path length difference between the object and reference beams can no longer be kept constant. This vibration-induced optical path length change will then be confounded with the signal of interest originating from the surface topography of the test object, e.g., a magnetic disc surface.

[0007] An effective solution to reduce the effect of environmental vibrations in interferometers is to translate the optical path length change caused by body movement into both the reference beam and the object beam. Such interferometers are known as common-path interferometers. There are three types of common-path interferometers; the heterodyne interferometer, the interferometer with a bifringent lens, and the scanning shearing interferometer. A common feature of these interferometer designs is the use of a single lens to deliver two beams to the object surface. The two beams are offset in striking the target surface. The two beams are typically generated by using a birefringent lens or a Wollaston prism. However, in these designs the separation distance "d" between the two beams as they strike the target surface is fixed. Moreover, the separation distance is limited by the numerical aperture of the lens and / or Wollaston prism. The maximum measurable spatial frequency is subsequently limited by these components.

[0008] Therefore, a need exists for an optical interferometer that insures a constant optical path length difference between the object and reference beams while the disc is experiencing the environmental vibration, which should cause the disc surface moving up and down. Still further, a need exists for an optical interferometer that permits adjustment of the separation distance between the two beams as they strike the target surface.

SUMMARY OF THE INVENTION

[0009] This disclosure describes a surface profiler using a dual-beam interferometer. The interferometer tool is designed to provide an optical, non-contact testing method for measuring and characterizing ultra-smooth surfaces. Examples of applications for the interferometer tool include the surfaces of magnetic recording discs and of semiconductor wafers.

[0010] The interferometer of the present invention is a common-path interferometer. The interferometer directs two beams focused at two distinct points on the testing surface. An offset distance "d" between the two beams is provided on the target surface. In the present invention, the separation distance "d" is adjustable. The interferometer requires neither a birefringent lens nor a Wollaston prism to generate the two separated beams; but uses instead known optical components. The feature of adjustable separation distance in the interferometer provides an efficient and accurate hardware low pass filter with which to meet the different spatial frequency requirements for various applications. Further, the reduced sensitivity to the environmental vibration qualifies this type of interferometer for applications requiring a portable device.

[0011] Generally, the optical interferometer first comprises a light source for generating a light beam. In one arrangement, the light beam is initially in the P-polarization state. The light beam is first directed to a first beam splitter. The beam splitter receives the light beam, and divides it into first and second beams. The first and second beams are of substantially equal intensity.

[0012] A half wave plate is provided for receiving the second beam from the first beam splitter. The half wave plate converts the second light beam from its P-polarization state to the S-polarization state.

[0013] The optical interferometer also comprises a polarizing cube beam splitter. The polarizing cube beam splitter receives and transmits the first light beam to the reflective surface, i.e., the test object. The polarizing cube beam splitter further receives and reflects the second light beam to the reflective surface. The first and second light beams are directed such that the first and second light beams are received at the reflective surface an offset distance "d" apart.

[0014] The first and second light beams are reflected back to the first beam splitter. Upon reflection, the light beams are split again and then the beams that travel in a same direction will be recombined. The process of splitting and recombining beams forms new first and second light beams. The new second light beam is constructed by the half intensity of the first beam and the half intensity of the second beam, and produces interference fringes as a result of the modulation of the optical path length difference between the new first and second beams. The new second light beam is directed to a photodiode. The photodiode receives the new second light beam, and converts the intensity of new second beam into electrical signals. These signals are representative of irregularities in the target surface and are later processed for analysis.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0016] Figure 1 presents a schematic diagram of parts comprising the dual beam optical interferometer of the present invention, in one embodiment.

[0017] Figure 2 is a schematic representation of a target surface, such as the upper surface of a magnetic disc. Two beams as generated in the diagram of Figure 1 are seen striking the target surface in offset fashion.

DETAILED DESCRIPTION OF THE INVENTION

[0018] **Figure 1** presents a diagram of a dual-beam, common path optical interferometer **100** of the present invention, in one embodiment. As the title implies, two beams **110** and **120** are generated through the interferometer **100**. The beams **110**, **120** are directed towards a target surface **150** under analysis. In the exemplary arrangement of **Figure 1**, the target surface **150** is a mirror-like, highly reflective, ultra-smooth disc surface, such as the surface of a magnetic data storage disc. However, it is understood that the present invention has utility in measuring smoothness of other smooth surfaces, such as silicon dioxide wafers.

[0019] In the present apparatus, a light source **200** is first provided. Preferably, the light source **200** defines a He-Ne laser. The laser **200** supplies a single, polarized laser beam **105**, in which the beam **105** is continuous. The beam 105 may be in either the P-polarization state or the S-polarization state, depending upon the configuration of other components as will be shown.

[0020] The polarized beam **105** is transmitted through an optical isolator **250**. The optical isolator **250** serves to direct the light beam **105**, and prevents the light beam **105** from returning to the laser **200** during the disc testing process. An example of a suitable optical isolator is product no. 501010 manufactured by Linos Photonics.

[0021] Once the polarized beam **105** is transmitted through the optical isolator **250**, it is directed to a first beam splitter **240**. The beam splitter **240** is an intensity beam splitter. The beam splitter **240** divides the single beam **105** into two parts of substantially equal intensity. The two beams are designated as beam one **110** and

beam two **120**. Beam one **110** and beam two **120** each remain in their original state of polarization at this point. In the preferred embodiment for the method and apparatus of the present invention, the polarization state is the P-polarization state.

[0022] Each beam **110**, **120** is transmitted to a mirror. Beam one **110** is transmitted through the beam splitter **240** to mirror one **112**, while beam two **120** is redirected at 90 degrees by the first beam splitter **240** to mirror two **212**.

[0023] As shown in the diagram of **Figure 1**, mirror one **112** reflects beam one **110** at 45 degrees. Likewise, mirror two **212** reflects beam two **120** at 45 degrees. The result is that each beam **110**, **120** is redirected at 90 degrees towards the same location, i.e., a polarizing cube beam splitter **160**.

[0024] En route to the polarizing cube beam splitter **160**, beam one **110** passes through a long working distance objective ("LWO one") **114**. LWO one **114** serves to focus beam one **110** onto a target surface **150**. Beam one **110** passes through the polarizing cube beam splitter **160** before hitting the target surface **150**. Because the beam **110** is in its P-polarization state, it is transmitted essentially straight through the cube beam splitter **160** and onto the target surface **150**.

[0025] Referring back now to beam two **120**, beam two **120** moves from mirror two **212** and also moves towards a long working distance objective. In this case, the long working distance objective is "LWO two" **124**. However, beam two **120** passes through a half-wave plate ("HWP") **126** before it is focused onto the target surface **150** by LWO two **124**. The HWP **126** is aligned so that the transmitted beam **120'** consists primarily of S-polarized light. Thus, the light **120'** received and focused by the long working distance objective two **124** is in the S-polarization state.

[0026] The S-polarized beam **120'** is received by the cube beam splitter **160**. The S-polarized beam **120'** is not transmitted through the cube beam splitter **160**, but is reflected onto the target surface **150** at a designated angle. In the arrangement shown in **Figure 1**, the reflection angle is 45 degrees.

[0027] In the diagram of **Figure 1**, it can be seen that beam one **110** and beam two **120'** do not strike the target surface **150** at the same location. In this respect, a distance "**d**" is defined by the separation between the two target strikes. This distance is created by virtue of placement of mirror one **112**.

[0028] In one arrangement, the objective LWO one **114** and mirror one **112** are built together as a block assembly. The block assembly is shown schematically in phantom at **118**. The assembly **118** is connected to a piezoelectric translator (not shown). The piezoelectric translator provides movement of the block **118** parallel to beam one **110** with an accuracy and resolution of less than 1 nanometer resolution. Bilateral movement of the block **118** is shown by arrow "**a**." This allows the apparatus **100** to accurately control and adjust the separation distance "**d**" between beam one **110** and beam two **120** as the beams **110**, **120** strike the target surface **150**.

[0029] **Figure 2** is a schematic representation of a target surface **150**, such as the upper surface of a magnetic disc. Two beams **110**, **120'** as generated in the diagram of **Figure 1** are seen striking the target surface **150** in offset fashion. Beam one **110** and beam two **120'** reflect off the target surface **150**. The reflected beams are shown as **210** and **220**, respectively. Thus, **Figure 2** is an enlarged view of a portion of **Figure 1**. In **Figure 1**, the target surface **150** appears planar. However, in the enlarged view of **Figure 2**, a surface irregularity is visible.

[0030] It will be understood by those of ordinary skill in the art that a magnetic disc surface is not always perfectly planar, but may have topographical variations. In the view of **Figure 2**, a topographical variation is demonstrated by local amplitude "**dH**." A magnetic disc having a significant surface amplitude **dH** within a short wavelength is considered defective.

[0031] After striking the mirror-like surface **150**, each beam **110**, **120'** is reflected back towards the polarizing cube beam splitter **160**. The beams **210**, **220** reflect back from the focal points along their respective original paths. Thus, reflected beam one **210** returns through the LWO one **114**, against mirror one **112**, and back

to the original beam splitter **240**. Reflected beam two **220** reflects against the polarizing cube beam splitter **160**, passes through the LWO two **214**, reflects again against mirror two **212**, and returns to the intensity beam splitter **240**. Beam two **220** returns to its original polarization state after transmitting through half wave plate **126**. Therefore, the beams **210** and **220** can interfere with each other once they recombine again at beam splitter **240**. The two reflected beams **210**, **220** are each split at the original beam splitter **240**. The reflected first beam **210** splits into beams **410** and **411** Beam **410** travels back towards optical isolator **250**, while beam **411** reflects to a photodiode **300**. In similar fashion, the second reflected beam **220** also splits into two beams, to wit, beams **420** and **421**. Beam **420** is reflected towards the optical isolator **250**, while beam **421** travels on to the photodiode **300**. Each beam **410**, **411** and **420**, **421** is comprised in approximately 50/50 ratios of the reflected first **210** and second **220** beams. A new recombined first beam **310** is thus formed by beams **410** and **420**, and a new recombined second beam **320** is thus formed by beams **411** and **421** at the intensity beam splitter **240**.

[0032] The newly constituted first beam **310** travels towards to the laser **200**. However, the new first beam **310** is blocked by the optical isolator **250** before it returns into the laser **200**. The newly constituted second beam **320** travels towards the photodiode **300**. This new second beam **320** received at the photodiode **300** produces interference fringes as a result of the modulation of the optical path length difference between the two beams **210, 220**.

[0033] The photodiode **300** captures these moving or changing fringes, which are observed as temporal variations in light intensity. The photodiode **300** then delivers a voltage signal proportional to the temporal light intensity change. This voltage signal "s," in turn, can be analyzed by subsequent digital signal processing as is known in the art.

[0034] The signals, I, detected by the photodiode **300** are described by:

[0035] $$I = I_1 + I_2 + 2\sqrt{I_1 \cdot I_2} \cdot \cos(\phi) \qquad (1)$$

[0036] where, I_1 and I_2 are the intensities of beam **411** and beam two **421**, respectively, and Ø is the phase difference between the two beams **411 (or 210)**, **421 (or 220)**. The phase difference Ø is a function of the optical path length difference, ΔL, between the two beams **210, 220**, which is presented in the equation:

[0037] $$\phi = \frac{2\pi\Delta L}{\lambda} \quad (2)$$

[0038] where, λ is the wavelength of the laser light.

[0039] Based on the geometry of **Figure 2**, which shows a magnified view of the beams' focusing area, ΔL can be described by:

[0040] $$\Delta L = 2(d + dH) \quad (3)$$

[0041] where *d* is the separation of beam one **110** and beam two **120'**, and *dH* is the height difference between the two focal points of beam one **110** and beam two **120'** on the object surface **150**. Equation (2) can then be rewritten as:

[0042] $$\phi = \frac{4\pi d}{\lambda} + \frac{4\pi dH}{\lambda} = \Phi + \frac{4\pi dH}{\lambda} \quad (4)$$

[0043] The first term in the equation (4) is a constant because the beam separation ***d*** is pre-determined based on the minimum spatial wavelength required to be detected. Therefore, the phase angle Ø is a function of ***dH,*** which is itself a function of the local surface slope. By solving equations (1) and (4) based on the intensity value *I* detected from photodiode **300**, the local height difference *dH* can be obtained. Subsequently, the local slope ***dS*** can be calculated by:

[0044] $$dS = dH / d \quad (5)$$

[0045] If we assume that the surface profile can be described by f(x), as shown in **Figure 2**, then df/dx=slope, or df/dx≈dS. Here, dx is ***d,*** the separation of beam one **110** and beam two **120'**. The profile or topography of the surface **150** can then be calculated by integration of the slope information.

[0046] In equation (1), there are two other unknowns, to wit, I_1 and I_2, that must be resolved before equation (1) can be solved. These two unknowns can be obtained by using I_{max} and I_{min} techniques. The I_{max} and I_{min} techniques are described in J. Wang and I Grant, "*ESPI, Phase Mapping, NDT The Techniques Applied to Real-Time, Thermal Loading*," Applied Optics **34**, 3620-3627 (1995).

[0047] With the current optical setup, the approach for obtaining I_{max} and I_{min} can be determined by moving the block assembly **118** backward and forward with the piezoelectric translator in order to vary the optical path length difference between the two beams, ΔL, such that a full cycle or more of moving interference fringes are generated. As long as the moving distance is greater than laser light wavelength, a full cycle moving fringe will be generated. The intensities of the moving fringes can be detected by the photodiode **300**. From there, the I_{max} and I_{min} can then be obtained. We can then re-write Equation (1) as:

[0048] $$I = I_a + I_b \cdot \cos(\phi) \qquad (6)$$

[0049] where $I_a = I_1 + I_2 = \frac{I_{max} + I_{min}}{2}$ *and* $I_b = 2\sqrt{I_1 \cdot I_2} = \frac{I_{max} - I_{min}}{2}$.

[0050] The profiling dynamic range is determined by the local height difference, *dH,* which is caused by the slope of the surface topography. The maximum *dH* which can be observed without causing a phase unwrapping problem is given by the second term of Equation (2) when it is set equal to π.

[0051] $$\pi = \frac{4\pi dH}{\lambda} \qquad (7)$$

[0052] or

[0053] $$dH = \frac{\lambda}{4} \qquad (8)$$

[0054] A He-Ne laser has a known wavelength of 0.6328 μm. When using a He-Ne laser, the maximum *dH* is 0.133 μm. This range is much greater than the

maximum local slope on an ultra-smooth surface, such as a hard disc surface. For instance, a typical hard disc, whose surface topography in the circumferential direction can be depicted by a sinusoidal function with *5* μm amplitude, or 10 μm peak-to-peak in amplitude, has a maximum *dH* of 0.004 μm for a radius of 25.4 mm and a sampling interval *d* of 10 μm. Therefore, this interferometer does not require phase unwrapping for most applications involving smooth surfaces. This increases the accuracy of the measurement and reduces the data processing time.

[0055] Various applications may be made with the dual beam interferometer of the present invention. Because the body movement between the profiling interferometer **100** and the testing object **150** will have little or no effect on the surface topography measurement, this type profiler **100** is well-suited to portable applications. For instance, the profiler **100** could be used for measuring HMS_Wq of the disc **150** on all kind of spindles, include measuring the discs in assembled hard disk drives. The profiler **100** may also be used for measuring disc edge roll-off without the need for an ultra-flat motion stage.

[0056] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof. For instance, the light source **200** may generate a continuous light beam **105** that is in the S-polarization state rather than the P-polarization state. In this instance, the half wave plate **126** would be in the path of beam one **110** rather than in the path of beam two **120**.